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(54) **ACTIVE COMMUNICATIONS BUS POWER HARVESTER FOR DIFFERENTIAL SIGNAL COMMUNICATION SYSTEM**

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H02J 7/00 (2006.01)

(52) **U.S. Cl.** **320/137**

(58) **Field of Classification Search** 320/162, 320/137

See application file for complete search history.

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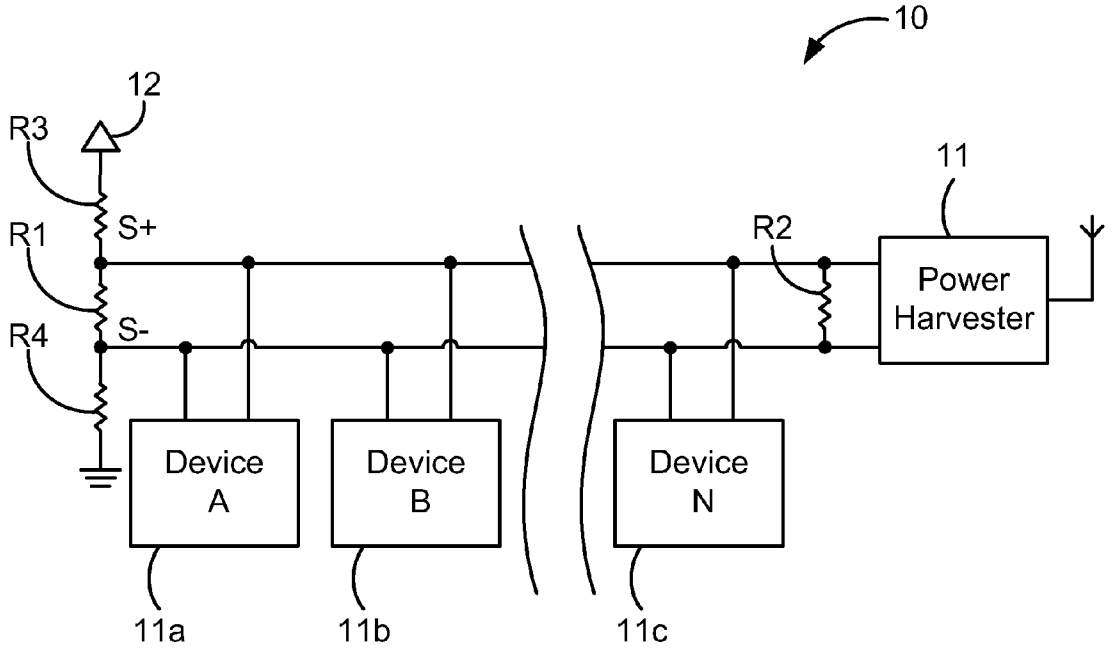
(57) **ABSTRACT**

A balanced differential signal communication system having at least two data lines connecting multiple nodes in series, each node comprising a signal generator for applying signals to the data lines that produce a controllable differential voltage across the data lines; a rechargeable storage device for receiving electrical energy from the data lines to charge the storage device; at least one device coupled to the storage device for receiving electrical energy from the storage device; and a controllable converter coupling the data lines to the storage device for controlling the charging and discharging of the storage device with power captured from the data lines.

16 Claims, 4 Drawing Sheets



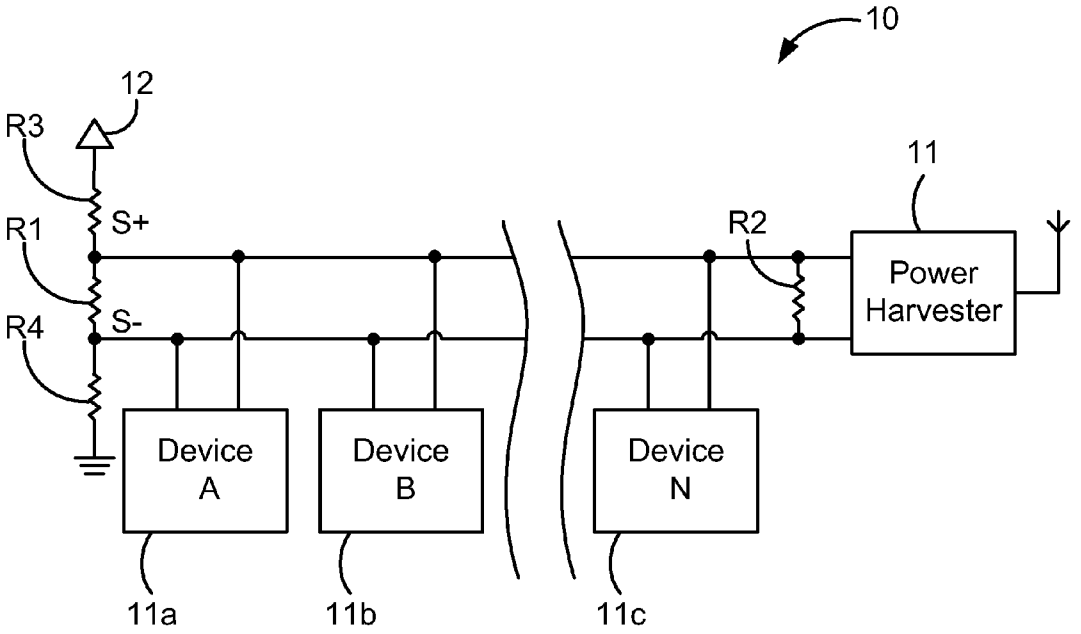

10
12
R3
11
R1
S+
R2
Power
Harvester
R4
S-
Device
A
Device
B
Device
N
11a
11b
11c

FIG. 1

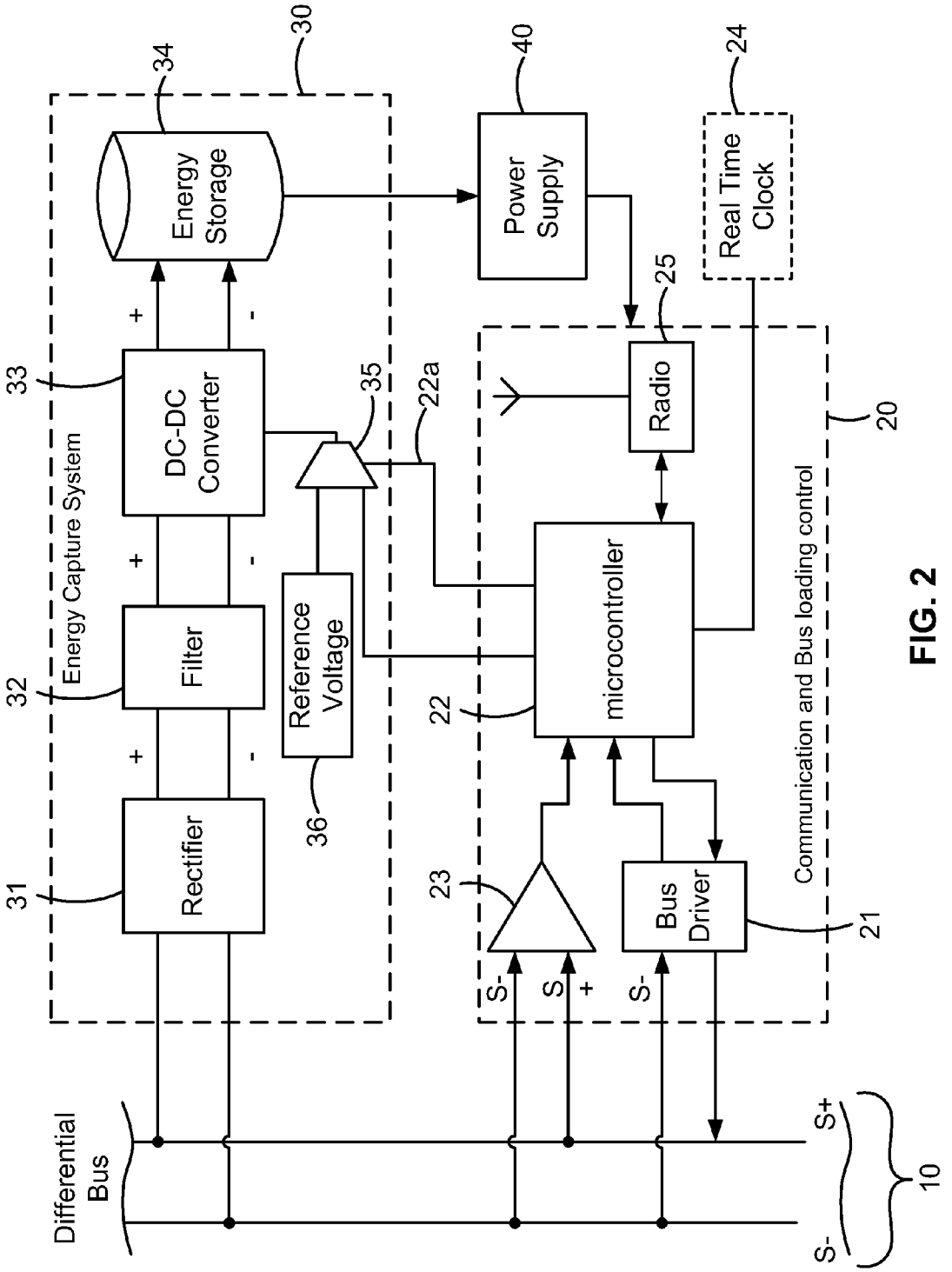

Energy Capture System
Communication and Bus loading control
Energy Storage
Power Supply
Real Time Clock
DC-DC Converter
Radio
Filter
Reference Voltage
microcontroller
Rectifier
Bus Driver
Differential Bus
S-
S+
S-
S+
S-
30
34
40
24
33
35
22a
25
20
32
36
22
31
23
21
10

FIG. 2

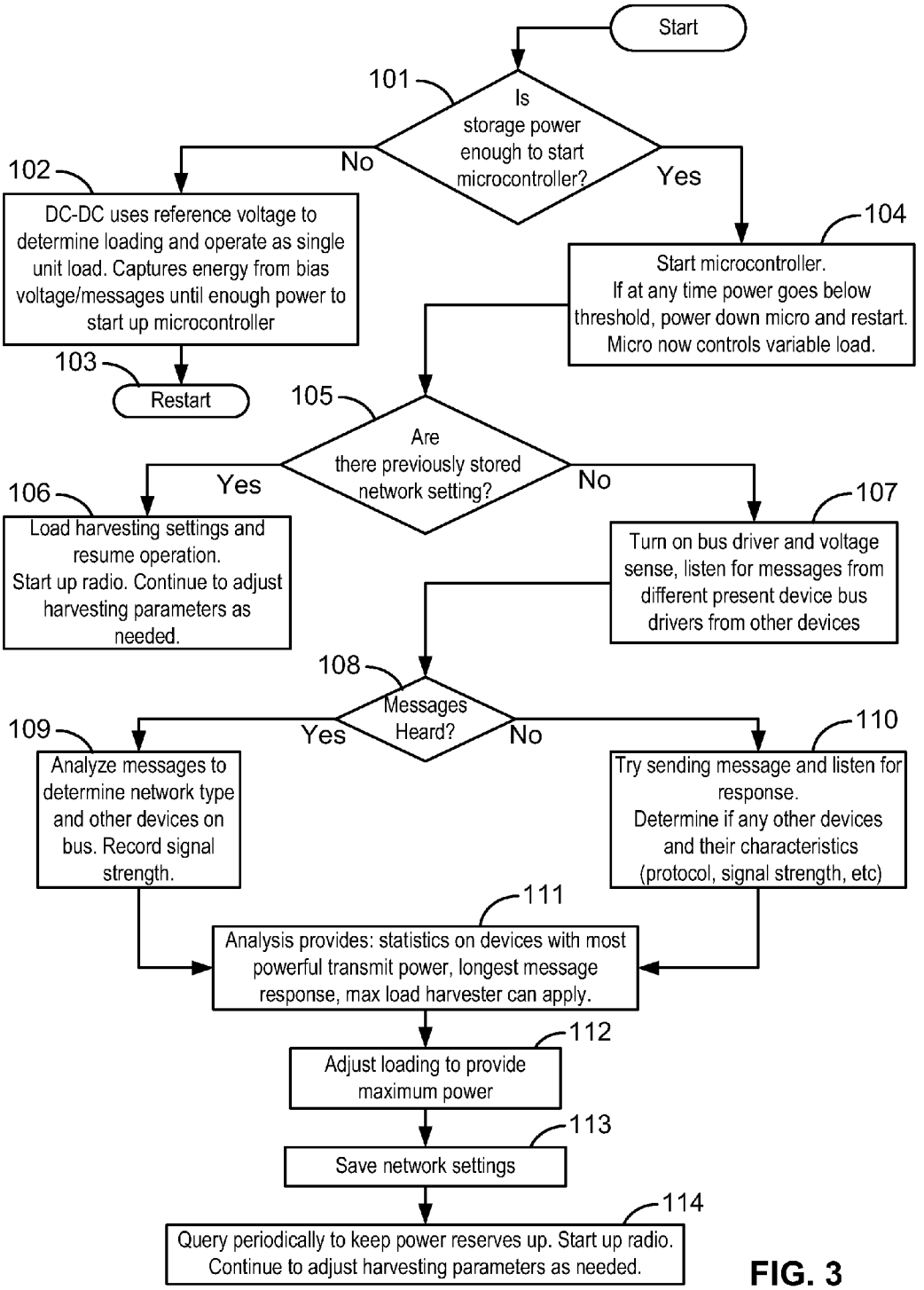

Start
101
Is storage power enough to start microcontroller?
No
Yes
102
DC-DC uses reference voltage to determine loading and operate as single unit load. Captures energy from bias voltage/messages until enough power to start up microcontroller
103
Restart
104
Start microcontroller. If at any time power goes below threshold, power down micro and restart. Micro now controls variable load.
105
Are there previously stored network setting?
Yes
No
106
Load harvesting settings and resume operation. Start up radio. Continue to adjust harvesting parameters as needed.
107
Turn on bus driver and voltage sense, listen for messages from different present device bus drivers from other devices
108
Messages Heard?
Yes
No
109
Analyze messages to determine network type and other devices on bus. Record signal strength.
110
Try sending message and listen for response. Determine if any other devices and their characteristics (protocol, signal strength, etc)
111
Analysis provides: statistics on devices with most powerful transmit power, longest message response, max load harvester can apply.
112
Adjust loading to provide maximum power
113
Save network settings
114
Query periodically to keep power reserves up. Start up radio. Continue to adjust harvesting parameters as needed.

FIG. 3

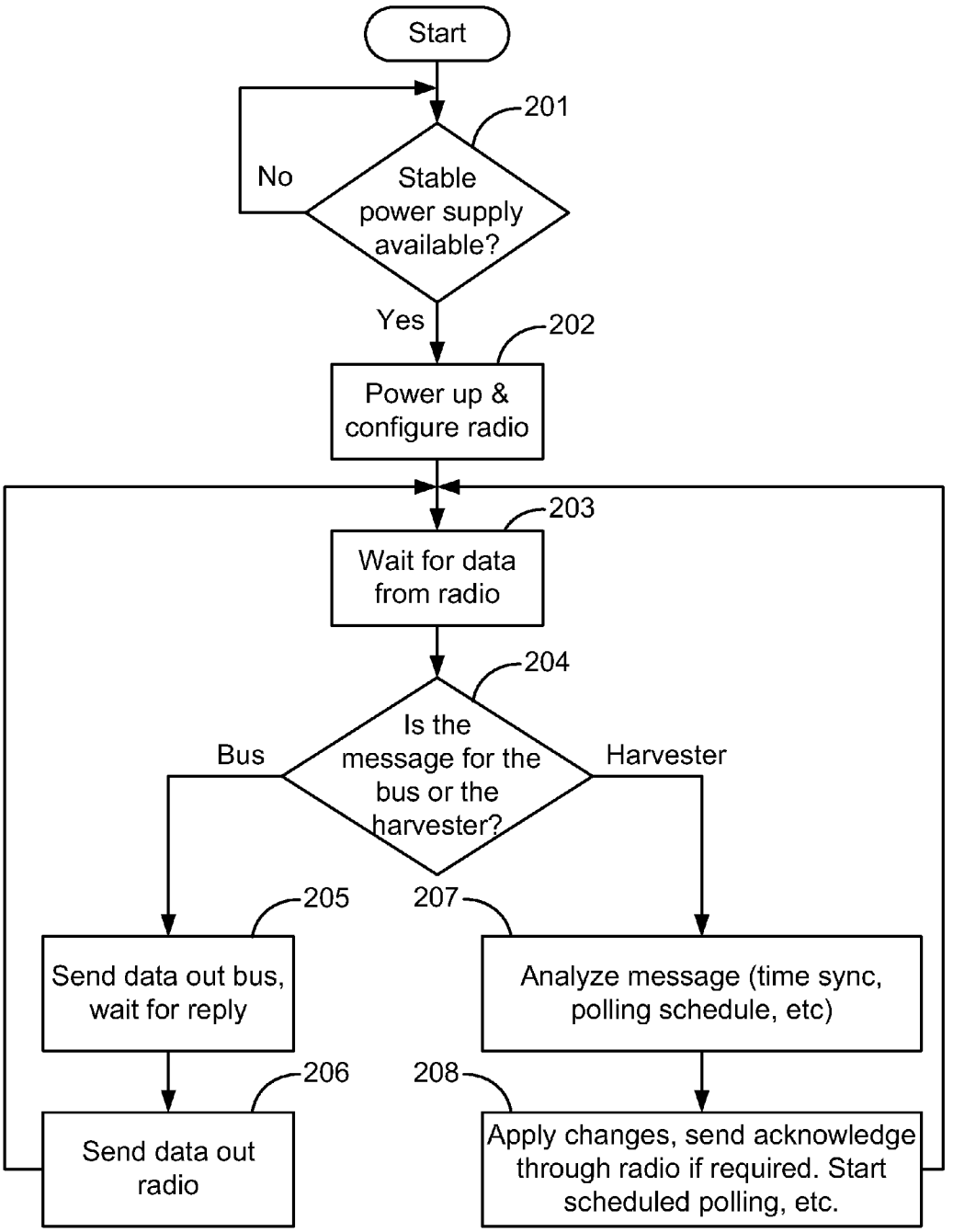

Start
201
No
Stable power supply available?
Yes
202
Power up & configure radio
203
Wait for data from radio
204
Is the message for the bus or the harvester?
Bus
Harvester
205
207
Send data out bus, wait for reply
Analyze message (time sync, polling schedule, etc)
206
208
Send data out radio
Apply changes, send acknowledge through radio if required. Start scheduled polling, etc.

FIG. 4

ACTIVE COMMUNICATIONS BUS POWER HARVESTER FOR DIFFERENTIAL SIGNAL COMMUNICATION SYSTEM

FIELD OF THE INVENTION

The present invention relates generally to supplying power to devices coupled to a differential signal communication system by harvesting electrical power from data lines of the communication system.

BACKGROUND

Differential signal communication systems are in widespread use. For example, RS-485 is a well known serial digital communication system that uses balanced differential signals for communicating with computers and other devices. RS-485 allows multiple devices to communicate at half-duplex on a single pair of wires, plus a ground wire, over long distances. Both the length of the network and the number of nodes can easily be extended using a variety of different repeater products that are readily available. The properties of differential signals provide high noise immunity and long distance capabilities.

RS-485 is the most versatile communication standard in the standard series defined by the EIA, as it performs well for connecting data terminal equipment (DTE) directly without the need of modems, for connecting several DTE's in a network structure, for communicating over long distances, and for communicating at fast communication rates. RS-485 is currently a widely used communication interface in data acquisition and control applications where multiple nodes communicate with each other. RS-485 signals are floating with each signal being transmitted over a S+ line and a S− line. The RS-485 receiver compares the voltage difference between the two lines, rather than the absolute voltage level on a single line.

RS-485 interfaces are often preferred for data acquisition and control applications because RS-485 is capable of internetworking multiple transmitters and receivers in the same network. High-resistance RS-485 inputs allow a large number of nodes to be used, and RS-485 repeaters can be used to increase the number of nodes even more.

BRIEF SUMMARY

The present disclosure provides a balanced differential signal communication system having at least two data lines connecting multiple nodes in series, each node comprising a signal generator for applying signals to the data lines that produce a controllable differential voltage across the data lines; a rechargeable storage device for receiving electrical energy from the data lines to charge the storage device; at least one device coupled to the storage device for receiving electrical energy from the storage device; and a controllable converter coupling the data lines to the storage device for controlling the charging of the storage device with power captured from the data lines.

One implementation includes a microcontroller coupled to the controllable converter and producing a control signal that affects the amount of power captured from the data lines by the converter; a multiplexer coupled between the microcontroller and the converter and having a pair of input terminals for receiving a pair of input signals, an output terminal, and a control input for receiving a control signal from the microcontroller for selecting which input signals are included in the output signal produced at the output terminal, one of the inputs receiving the control signal produced by the microcontroller; and a source of a fixed reference voltage coupled to the other of the inputs to the multiplexer. The microcontroller may be programmed to send messages via the data lines to other nodes coupled to the data lines to cause the other nodes to respond to the messages via the data lines, and the converter captures power from the responses for recharging the storage device.

One embodiment includes a sensor coupled to the data lines for sensing the voltage differential between the data lines and supplying a signal representing the voltage differential to the microcontroller, and a microcontroller is programmed to use the signal representing the voltage differential to determine a load that can be imposed on the data lines without interfering with communications on the data lines. The converter is preferably controllable to vary the load that the converter imposes on the data lines, so that the load does not interface with communicating via the data lines.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may best be understood by reference to the following description taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a block diagram of an RS-485 communication system that includes multiple nodes and a power harvesting device for harvesting electrical power from the data lines of the bus.

FIG. **2** is a block diagram of one of the nodes in the system of FIG. **1**.

FIG. **3** is a flow chart of a program executed by the microcontroller in the node of FIG. **2** to control the harvesting of electrical power from the bus.

FIG. **4** is a flow chart of a program executed by the microcontroller in the node of FIG. **2** to control radio/bus messaging.

DETAILED DESCRIPTION

Although the invention will be described in connection with certain preferred embodiments, it will be understood that the invention is not limited to those particular embodiments. On the contrary, the invention is intended to cover all alternatives, modifications, and equivalent arrangements as may be included within the spirit and scope of the invention as defined by the appended claims.

Turning to the drawings, FIG. **1** is a functional block diagram of an RS-485 communication system that includes a differential bus **10** is formed by a pair of data lines S+ and S−, and multiple nodes formed by devices **11***a*, **11***b* . . . **11***n* coupled to the bus **10** at different points along the length of the bus. An RS-485 communication channel can be shared by multiple receivers and multiple senders. In the illustrative embodiment, the bus **10** is terminated by resistances R**1** and R**2** at opposite ends, and a bias voltage is supplied to one end of the bus from a source **12** through voltage divider formed by a pair of resistors R**3** and R**4** in combination with the terminating resistor R**1**. For high bit rates and long wiring runs, termination resistances are necessary on both ends of the bus **10** to eliminate reflections, but not at drop points along the bus. High bit rates are possible because the transition between logical 0 and logical 1 is only a few hundred millivolts, and currently available RS-485 drivers can achieve bit rates of at least 35 mbps.

Although FIG. **1** illustrates an RS-485 two-wire multi-drop bus, it will be understood that an RS-485 network can also be connected in a four-wire mode, using four data wires and an

additional signal ground wire. In a four-wire network, one node is a master node and all others are slave nodes. The network is connected so that the master node communicates to all slave nodes, and all slave nodes communicate only with the master node. Since the slave nodes never listen to another slave response to the master, a slave node cannot reply incorrectly to another slave node. RS-422 systems are also use balanced differential signals, using a dedicated pair of wires for each signal, a transmit pair, a receive pair and an additional pair for each handshake/control signal used (if required). In a "two-wire" network the transmitter and receiver of each device are connected to a twisted pair. "Four-wire" networks have one master port with the transmitter connected to each of the "slave" receivers on one twisted pair. The "slave" transmitters are all connected to the "master" receiver on a second twisted pair. In either configuration, devices are addressable, allowing independent communications with each node.

FIG. **2** is a more detailed illustration of one of the node devices **11**, which includes a communication and bus loading control **20** and an energy capture system **30**, both of which are coupled to the two data lines S+ and S− of the bus **10**. As is well known, the data lines S+ and S− are preferably in the form of a twisted pair, to provide noise immunity. The energy capture system **12** supplies electrical power to a power supply **40** that powers the communication and bus loading control **11**.

Within the communication and bus loading control **20**, an RS-485 bus driver **21** sends signals to, and receives signals from, the data lines S+ and S− of the bus **10**. The driver **21** delivers received signals to a microcontroller **22**, and receives signals from the microcontroller **22** for delivery to the bus **10**. Only one device can drive the data lines at a time, so the drivers at the various nodes must be put into a high-impedance mode (tri-state) when they are not in use. An RS-485 driver is typically enabled and disabled by an RTS control signal from an asynchronous serial port. Setting the RTS line to a high (logic 1) state enables the driver, while setting the RTS line to a low (logic 0) state puts the driver into a tristate condition that in effect disconnects the driver from the bus, allowing other nodes to transmit over the same pair of data lines. The RS-485 driver typically returns to its high impedance tri-state within a few microseconds after data has been sent, so it is not necessary to have delays between data packets on the RS-485 bus. These tristate capabilities of RS-485 nodes allow a single pair of wires to share transmit and receive signals for half-duplex communications.

The microcontroller **22** also receives the output of an operational amplifier **23** that has two inputs coupled to the two data lines S+ and S−, so that the output of the amplifier **23** represents the difference between the voltage levels on the two data lines S+ and S−. The microcontroller **22** also receives inputs from a real time clock **24** and a radio transceiver **25**, and delivers control signals to the energy capture system **30**, as will be discussed in more detail below. The transceiver **25** is typically a generic low power radio transceiver, such as a ZigBee radio, or the transceiver may be replaced with a signal/protocol converter.

The energy capture system **30** includes a rectifier **31** having a pair of inputs coupled to the two data lines S+ and S−, producing a rectified output that is smoothed by a filter **32** and then supplied as the DC input to a controllable DC-to-DC converter **33**. The DC output of the converter **33** is supplied to an energy storage device **34**, such as a rechargeable battery or an ultra capacitor. The output of the storage device **34** is connected to the power supply **40** that supplies power to the communication and bus loading control **20**, including the microcontroller **22** and the radio **25**. When the storage device is a rechargeable battery, it may be installed pre-charged to reduce the initial charge and discovery time, or it may be initially charged by some other means such as a USB plug-in to a computer.

To control the charging of the energy storage device **34**, the microcontroller produces control signals for a multiplexer **35** that also receives a reference voltage form a reference voltage source **36**. The multiplexer **35** selects one of its two inputs, from the microcontroller **22** and the reference voltage source **36**, for application to the converter **33**. The selection is controlled by a "select" signal generated on output line **22***a* from the microcontroller **22** and applied to the select input of the multiplexer **35**, which determines which of the two multiplexer inputs is supplied to the converter **33**. It will be understood that either a digital or analog multiplexer may be used, depending on the type of control desired for the converter **33**. This control of the converter **33** enables the system **30** to capture small amounts of energy from the biasing voltage on the bus **10**, or to capture larger amounts of energy from data signals on the bus when the data lines S+ and S− are driven by other devices on the bus. By controlling the converter, the system is able to vary the load it puts on the bus **10** to capture more or less power, while ensuring that the load does not interfere with communications. The converter may be controlled to change not only the power captured from the bus **10**, but also the impedance it presents to the bus to improve communication and/or the power harvesting capabilities.

Upon connection to the bus **10**, the converter **33** and the storage device **34** capture a small amount of power from the biasing circuit for the bus **10**. The converter **33** varies its load to draw as much power as possible from the bus biasing circuit without exceeding the specification of the communications system or dropping the biasing voltage below the appropriate threshold for the applicable communications standard. Any communications that occur on the bus **10** allow the converter **33** to charge the storage device **34** faster than just the biasing voltage, and those communications can also be used to identify the type of network or protocol being used, as described in more detail below.

After the storage device **34** has accumulated enough energy to enable the microcontroller **22** and the driver **21** to generate a request, they transmit a harmless request to the other nodes on the bus **10**, such as a Modbus read or identify request. The microcontroller may identify the desired type of communication automatically by monitoring traffic on the bus **10**, or the microcontroller may have been pre-configured for a certain setting. If there is no response to a request generated by the microcontroller **22** and the driver **21**, the converter **33** continues charging the storage device **34** from the bias voltage while the microcontroller **22** continues to generate different types of messages or targets different nodes until a response is received.

After a response is received, the power-harvesting system has a better source of power and can begin issuing additional requests to detect other protocols or devices on the network. For example, certain nodes on the bus **10** may have stronger drivers, which can be detected by varying the load on the network while listening for a response, or certain nodes may respond faster or support other commands that produce longer responses and therefore supply more power for each request. The microcontroller may be programmed to look for the option that will provide the most power for charging the storage device **34**, both in terms of the device's driving capabilities and the ratio of power received to power required to transmit.

In the illustrative example with the radio **25**, the microcontroller **22** can turn on the radio **25** and thus begin wireless

communications after a stable source of energy has been obtained and sufficient energy has been stored. Other nodes on the bus **10** can be polled as needed to maintain the required power.

When the illustrative device is acting as a bridge or converter between a radio network and a wired communications bus, incoming requests can be buffered while power is being harvested from the wired bus. Then a message can be transmitted from the wireless network, and any response will be forwarded back onto the radio network. The radio **25** or the entire device may be designed to go into a low power "sleep" state and only power up when traffic is received from the wired communications bus, or in response to a periodic radio timer.

FIG. **3** is a flow chart of a power-up sequence for the power harvester illustrated in FIG. **2**. Step **101** determines whether the energy storage device **34** has accumulated enough power to start the microcontroller **22**, and if the answer is negative, step **102** indicates that the DC-to-DC converter **33** uses the fixed reference voltage from source **36** to determine the loading on the bus **10**. That is, the converter **33** operates as a single unit load, capturing energy from the bias voltage and any messages on the data lines S+ and S− until enough power is accumulated in the storage device **34** to start up the microcontroller **22**.

When the response at step **101** is affirmative, the microcontroller **22** is started at step **104** so that the balance of the steps in FIG. **3** can be executed by the microcontroller. If at any time the power available from the storage device **34** drops below a preselected threshold, the microcontroller **22** is powered down and re-started when the accumulated power again rises above that threshold. After the microcontroller **22** has been started, the microcontroller **22** controls the variable load imposed on the bus **10** by the DC-to-DC converter **33**, via the control signal applied to the select input of the multiplexer **35** by the microcontroller.

From step **104**, the system advances to step **105**, which determines whether there are any previously stored network settings. If step **105** yields an affirmative answer, the system proceeds to step **106** to load any settings for the power harvester settings and resume operation, including turning on the radio **25**. The system then advances to step **114**, which queries the network settings periodically and adjusts the power-harvesting parameters as needed to maintain a maximum power reserve.

When step **105** yields a negative response, indicating that there are no previously stored network settings, the system advances to step **107** to turn on the bus driver **21**, to turn on the voltage differential-sensing amplifier **23**, and to listen for messages. The system then advances to step **108** to listen for messages. When a message is detected, step **108** produces an affirmative response, which advances the system to step **109** which analyzes the message to collect data from the message, such as network type, other devices on the bus and signal strength. The collected data is then analyzed at step **111** to determine desired statistics such as the identity of devices having the most transmit power, the longest message response, the maximum load the harvester can apply to the bus **10** without adversely affecting communications, etc.

When no message is detected, step **108** yields a negative response, the system advances to step **110** to transmit a message via the bus driver **21** and then listen for a response. Any response is used to collect the same type of data collected at step **109**, namely, network type, other devices on the bus signal strength, etc. The collected data is then analyzed at step **111** to determine desired statistics such as the identity of devices having the most transmit power, the longest message response, the maximum load the harvester can apply to the bus **10** without adversely affecting communications, etc.

From step **11**, the system advances to step **112** to adjust the loading on the bus **10** to provide maximum power to recharge the storage device **34**, and then those network settings are saved at step **113**. Then step **114** queries the network settings periodically and adjusts the power-harvesting parameters as needed to maintain a maximum power reserve. It will be understood that the loading on the bus is adjusted by the DC-to-DC converter **33** in response to the output signal received by the converter from the multiplexer **35**, which in turn is controlled by the control signal applied to the select input of the multiplexer **35** by the microcontroller **22**.

FIG. **4** is a flow chart of a routine executed by the microcontroller **22** to control messaging operations via the radio **25** and the bus **10**. The radio **25**, which can wait to be triggered by another device or can query a central device on power up, serves to synchronize multiple power harvesters and to relay messages between the bus **10** and another location, either on request or as part of a scheduled operation.

The routine in FIG. **4** begins at step **201**, which determines whether a stable power supply is available, based on stored data relating to power supplied to the microcontroller from the power supply **40** over a selected time interval. This step repeats until it produces an affirmative response, which advances the system to step **202** to power up and configure the radio **25**. Step **203** then waits for data from the radio **25**, and advances to step **204** when such data is received. Step **204** determines whether the radio message is for the bus **10** or the power harvester. If the message is for the bus, the data is sent out on the bus **10** at step **205**, after being reformatted by the microcontroller **22** if necessary, and is then sent out on the radio **25** at step **206**. If step **204** determines that the radio message is for the power harvester, the routine advances to step **207** to analyze the message for information such as time synchronization, polling schedule, etc. Step **208** then applies any changes, sends an acknowledgment through the radio if required, starts scheduling polling, etc.

While particular embodiments and applications of the present invention have been illustrated and described, it is to be understood that the invention is not limited to the precise construction and compositions disclosed herein and that various modifications, changes, and variations may be apparent from the foregoing descriptions without departing from the spirit and scope of the invention as defined in the appended claims.

The invention claimed is:

1. A balanced differential signal communication system having at least two data lines connecting multiple nodes in series, each node comprising a signal generator for applying signals to said data lines that produce a controllable differential voltage across said data lines, a receiver coupled to said data lines for detecting said differential voltage, a rechargeable storage device coupled to said data lines for receiving electrical energy from said data lines to charge said storage device, at least one device coupled to said storage device for receiving electrical energy from said storage device, and a controllable converter coupling said data lines to said storage device for controlling the charging of said storage device with power captured from said data lines, wherein said signal generator generates signals for transmission to other nodes coupled to said data lines to stimulate said other nodes to generate signals for transmission via said data lines, to provide additional power to be captured by said converter from said data lines.

2. The balanced differential signal communication system node of claim **1** which includes a microcontroller coupled to

said controllable converter and producing a control signal that affects the amount of power captured from said data lines by said converter.

3. The balanced differential signal communication system of claim **1** in which said controllable converter imposes a DC-to-DC load on said data lines at a default level, and which includes control circuitry for overriding said default-level load to increase the DC-to-DC load on said data lines to increase the rate of charging said storage device.

4. The balanced differential signal communication system node of claim **1** which includes a bias voltage source coupled to said data lines for applying a bias voltage across said data lines.

5. The balanced differential signal communication system node of claim **1** which includes a voltage source and bias resistors connected across said data lines to maintain a minimum bias current flow in said data lines for noise suppression.

6. The balanced differential signal communication system node of claim **1** in which said controllable differential voltage has two different levels, representing the two states of a binary signal transmitted via said communication line.

7. The balanced differential signal communication system node of claim **1** in which said rechargeable storage device is a rechargeable battery or a capacitor.

8. The balanced differential signal communication system node of claim **2** in which said microcontroller is programmed to send messages via said data lines to other nodes coupled to said data lines to cause said other nodes to respond to said messages via said data lines, said converter capturing power from said responses for recharging said storage device.

9. The balanced differential signal communication system node of claim **1** in which said converter is controllable to vary the load that said converter imposes on said data lines, so that said load does not interface with communicating via said data lines.

10. The balanced differential signal communication system node of claim **2** which includes a sensor coupled to said data lines for sensing the voltage differential between said data lines and supplying a signal representing said voltage differential to said microcontroller, and said microcontroller is programmed to use said signal representing said voltage differential to determine a load that can be imposed on said data lines without interfering with communications on said data lines.

11. The balanced differential signal communication system node of claim **1** in which said load imposed by said controllable converter on said data lines is an adjustable resistive or reactive load.

12. The balanced differential signal communication system node of claim **2** which includes

a multiplexer coupled between said microcontroller and said converter and having a pair of input terminals for receiving a pair of input signals, an output terminal, and a control input for receiving a control signal from said microcontroller for selecting which input signals are included in the output signal produced at said output terminal, one of said inputs receiving said control signal produced by said microcontroller, and

a source of a fixed reference voltage coupled to the other of said inputs to said multiplexer.

13. A method of harvesting electrical power from a balanced differential signal communication system having at least two data lines connecting multiple nodes that include a signal generator for applying signals to said data lines to produce a controllable differential voltage across said data lines, and a receiver coupled to said data lines for detecting said differential voltage, said method comprising coupling a rechargeable storage device to said data lines through a controllable converter that charges said storage device with electrical energy captured from said data lines, coupling at least one device to said storage device for receiving electrical energy from said storage device, and generating signals for transmission to other nodes coupled to said data lines to stimulate said other nodes to generate signals for transmission via said data lines, to provide additional power to be captured by said converter from said data lines.

14. The method of claim **13** which includes rectifying non-DC energy removed from said data lines, said controllable converter imposes a DC-to-DC load on said data lines, and controlling said DC-to-DC load to adjust the rate of charging said storage device without interfering with communications on said data lines.

15. The method of claim **14** in which said DC-to-DC load is imposed on said data lines at a default level, and which includes overriding said default-level load to increase the DC-to-DC load on said data lines to increase the rate of charging said storage device.

16. The method of claim **13** which includes sending messages via said data lines to other nodes coupled to said data lines to cause said other nodes to respond to said messages via said data lines, said converter capturing power from said responses for recharging said storage device.

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